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EFFECTS OF RADIATION ON MATERIALS & COMPONENTS

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EFFECTS OF RADIATION ON MATERIALS & COMPONENTS

My presentation today will cover, briefly, the effects of the space radiation, both the particulate and the thermal, on space vehicle materials and components. I intend to discuss advanced missions in general rather than state requirements for specific missions.

We are obtaining two types of data in the radiation effects area -- engineering data on the effects of radiation on specific components and data leading to a better understanding of the basic mechanisms in radiation damage. Our interest in engineering data is for short-term design, while the basic data represents our major concern for long-term application.

High energy particle radiation can affect materials in two ways, by ionization and by atomic displacements. **** The first slide shows the approximate threshold doses for radiation damage for the more sensitive materials and components of both manned and unmanned spacecraft.

The damage thresholds are usually determined by noting when changes occur in some particular property of a material. The amount of damage due to ionization is usually proportional to the total energy absorbed in the material.

Displacement defects have a pronounced influence on the electrical behavior of semiconductors. The amount of damage due to displacements usually is determined by the number of irradiating particles impinging on the material.

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Although, the threshold doses for damage to most of the materials and devices shown are considerably larger than that required for man, there are at least two reasons why radiation damage to these materials and devices could be an important limiting factor in the operation of a manned vehicle.

1. First, it may be necessary for some of the materials and devices, such as optical glass and solar cells, to operate outside of a shielded crew compartment.

2. Second, a spacecraft may spend a much longer time in the radiation environment than do men if the vehicle remains aloft while men commute between it and earth.

To obtain a prediction of the useable lifetime for a particular material or device in a specific space application, one must consider the radiation damage induced in the device as a function of particle energy and the energy spectrum and total flux of the particle environment.

**** The next slide shows the energy dependence of proton induced damage in silicon normalized to the damage caused by 30 MeV protons. Because of their larger Rutherford scattering cross section, low energy protons are more effective in producing damage in silicon than are high energy protons.

**** The next slide shows the energy dependence of electron induced damage in P- and N-type silicon. The energy dependence is considerably more pronounced for P-type silicon. It should be noted that these curves are normalized to the respective damage rates in P- and N-type silicon for 1 MeV electrons and do not reflect the fact that the absolute damage rate in N-type silicon is considerably higher than in P-type.

These curves point out the importance for measurements of low energy protons < 30 MeV and for measurements of high energy electrons > 1 MeV.

Just how can we insure that a spacecraft will have the necessary radiation tolerance for a given mission? **** The next slide indicates various means of insuring radiation tolerance for space vehicles.

SHIELDING

One of the most common ways of avoiding radiation damage is to isolate sensitive components from the radiation environment with appropriate radiation shields. This is particularly true for manned systems.

MATERIAL AND COMPONENT REPLACEMENT

Another approach, to increase the radiation tolerance of a system, is to remove the radiation sensitive components and replace them with more tolerant components that can still perform the necessary functions. In some cases, such as photographic film, there presently are no simple and equally effective substitutes; and shielding is the only means of increasing radiation tolerance. However, field effect devices can be substituted for transistors, fused quartz can be substituted for glass, and saphire, in turn, can be substituted for fused quartz.

EXTRA OPERATING CAPACITY OR REDUNDANCY

The third method of insuring adequate radiation tolerance for a system is to provide extra operating capacity. This technique is particularly suitable for electronic circuits. The usefulness of this technique results from the fact that most devices do not have a well defined radiation limit but degrade gradually as the total integrated dose is increased.

The solution to radiation damage problems in space usually represents a combination of shielding, material replacement and redundancy. In order to determine the optimum combination, one needs to know:

1. the total flux and energy spectrum of the radiation environment;
2. the interaction of the radiation with materials; and
3. the effect of the interaction upon material or component performance.

The collection and assimilation of the radiation environment is a difficult but vital job. Recently, the Office of Space Sciences and Applications and the Office of Advanced Research and Technology of NASA jointly initiated a contract with the Aerospace Corporation for the collection, assimilation, and dissemination of the spatial energy flux of the trapped radiation environment. One of the objectives of this work is to obtain and maintain the best composite radiation environment for engineering uses. Dr. James I. Vette of Aerospace Corporation will be the principal investigator for this project.

In unmanned systems, radiation sensitivity of materials can be an important factor in limiting the useful lifetime of a space vehicle. In manned systems, however, the low radiation damage threshold for the crew will usually be more important in determining the time that the crew and vehicle remain in space.

Let me now turn your attention to the effects of the space thermal radiation environment on space vehicle materials and components.

**** The next slide shows the thermal spectrum from the sun. You will note that the ultraviolet portion of the spectrum represents about 9% of the total solar energy; the bulk of the solar energy being in the visible and infrared.

It is well known that the most degrading portion of the solar thermal radiation environment is the near ultraviolet (2200 - 4000Å). The effects of ultraviolet are felt most strongly by organic materials, which undergo structural alterations such as molecular cross-linking and decomposition. Paint pigments and other inorganic materials may be affected by the formation of color centers associated with the presence of impurities in the materials. For example, white dielectric materials, under excessive UV exposure, turn brown and suffer an increase in thermal absorptance. Metals and black surfaces are not significantly affected by ultraviolet energy.

A very important problem in the design of spacecraft is that of maintaining temperatures in the desired range. Here, one must consider not only solar radiation, but also planetary albedo, internal heating sources and the internal transmission of heat and re-radiation to space.

One step toward improving thermal design capability is to provide more accurate solar radiation simulation. We have an active program in this area covering the items shown in the next slide. ****

Most of the solar simulators presently use light sources developed for searchlights and for the motion picture industry. More intense sources having increased lifetimes and better matching with the actual solar spectrum are currently under development.

The complex optical systems needed for focusing the energy from light sources into a vacuum chamber are being analyzed in order to better predict performance and to permit optical mixing of sources.

The next two items on the chart, "Spectral Measurement" and "Facility Calibration," refer to a most urgent problem area -- that of improving and standardizing spectral measurement techniques for the calibration of facilities. A program aimed at eliminating this deficiency has been established at the National Bureau of Standards under NASA sponsorship.

The last item, "Thermal Modeling," stems from the constant increase in the size of solar simulation facilities. Several efforts are underway to establish scaling laws which will enable the use of thermal scale modeling and hopefully reduce the need for very large simulators.

We also have a large effort in the development of techniques which can be used to control spacecraft temperatures. The next slide **** illustrates one of the difficulties in controlling such temperatures. Here, the expected equilibrium temperature of an insulated flat plate exposed to solar radiation is shown as a function of distance from the sun. Each curve is for a plate having a different value for the ratio of absorptivity to emissivity -- or a/e -- which is a measure of the fraction of the incident energy which is collected and retained by the plate.

As you see, the temperature increases considerably as one moves closer to the sun with the absolute magnitude of the temperature depending on the a/e ratio. It is obvious from the figure, that if the distance between the plate and the sun is varied, to retain a constant temperature, the a/e ratio must also be varied. This is exactly the case with spacecraft. For vehicles operating over a wide range of distances from the sun, passive temperature control surfaces -- having constant a/e ratios -- are, in general inadequate. Consequently, we are concerned with the development of active -- variable a/e -- temperature control techniques.

Typically as spacecraft becomes larger and more complex, the requirements for more highly efficient solar reflectors becomes more and more urgent. The requirement for the knowledge of the a/e ratio for passive thermal control surfaces and surface coatings is more critical than in the case of active control devices. With either technique, however, one of the main problems is the development of stable surfaces or surface coatings which have a low solar a/e ratio.

**** The next slide shows the reflectance of zinc oxide, which is typical of the reflectance of highly efficient solar reflectors. The reflectance begins to fall off rapidly at wavelengths below 4400A and drops to less than 30% at 3800A. Approximately, 50% of the absorbed energy in the zinc oxide is due to the ultraviolet, a region containing less than 10% of the total solar energy.

In summary, knowledge of the absolute intensity and possible secular changes of the complete solar spectrum is are required for the optimum design of thermal control systems of spacecraft. Information concerning the ultraviolet is of prime importance because of its large contribution to the total energy absorption of many thermal control surfaces as well as the possible degradation of these surfaces.

FIGURES USED AT SYMPOSIUM ON SPACE "WEATHER" Arthur Reetz

1. Approximate Threshold Doses for Radiation Damage
2. Relative Proton Damage in Silicon
3. Relative Electron Damage in Silicon
4. Means of Insuring Radiation Tolerance
5. Solution of Radiation Damage Problems Knowledge of --
6. Solar Spectral Energy at Zero-Air-Mass
7. Solar Simulation Research
8. Temperature of an Insulated Flat Plate Heated by the Sun
9. Spectral Reflectance for Zinc Oxide Powder (99.80% Purity)